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RAPID SIMULATION OF FLAT KNITTING LOOPS BASED ON THE YARN TEXTURE AND LOOP GEOMETRICAL MODEL

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Abstract:

In order to create realistic loop primitives suitable for the fast computer-aided design (CAD) of the flat knitted fabric, we have a research on the geometric model of the loop as well as the variation of the loop surface. Establish the texture variation model based on the changing process from the normal yarn to loop that provides the realistic texture of the simulative loop. Then optimize the simulative loop based on illumination variation. This paper develops the computer program with the optimization algorithm and achieves the loop simulation of different yarns to verify the feasibility of the proposed algorithm. Our work provides a fast CAD of the flat knitted fabric with loop simulation, and it is not only more realistic but also material adjustable. Meanwhile it also provides theoretical value for the flat knitted fabric computer simulation.

Keywords:

Flat knitting; yarn texture; fast simulation; loop primitives

1. Introduction

In the simulation of the textile's appearance, the computer graphic techniques are used to display the ideas of the designers on the screen quickly and intuitively [1]. The application of these techniques has the potential for improving design efficiency, reducing development cost, and increasing the enterprises' productivity and responsiveness. As the unit of the textile, the yarn has been subject to extensive research efforts, and the technologies about it have been well developed [2]. The woven fabric is formed by interweaving the warp and weft following a regular pattern [3], and the yarn bends in a 1D manner during the interweaving process [4]. The knitted fabric is generated by bending the yarns into the cycles and then intermeshing them [5]. The loops take the form of the complicated 3D curves so that the texture at the surface distort and modify [6–7]. Therefore, the simulation of the knitted fabric is a difficult issue in the simulation study on the appearance simulation of the textile. It is also an important problem in the reality-based computer-aided design (CAD) system of the knitted fabric.

The established CAD applications that are currently available in the market keep the loop simulation techniques classified and only describe the simulation functions without releasing the algorithms used. The simulations of the knitted fabric's appearance is either based on the loop [8–9] or on the texture [10] at the surface of the textile. These two types of methods have their pros and cons. The loop-based method can be divided into two kinds: 2D and 3D; 3D simulation attracted much attention from scholars because of its ability to obtain the desired 3D simulation results by accurately describing the spatial structure of the loop. If the yarn is simulated with simple geometrical shapes, then the loop cannot display the yarn feather and twist effect. The use of complicated polygons for the simulation will incur heavy computational complexities and result in reduced speed [11], its application is limited. Comparatively, the advantage of 2D simulation is rapid, the disadvantage is that it is difficult to express the spatial structure and the lack of 3D feeling. In the method based on the appearance's texture, the texture features of a certain type of products are studied to simulate the knitted fabric using the algorithm that combines textures via patch quilting. Despite its realistic simulations, this simulation method has its limitations and cannot represent the joints between loops. The purpose of this paper is to devise realistic primitives of the loop that can be used for fast CAD of the flat knitted fabric. After the extraction or simulation of the surface texture of the yarn, the computation model for the transformation from the flat texture to the bent texture is constructed. Then, the reality of the loop is optimized based on the illumination variations at the surface of the yarn. Finally, this proposed method is implemented via VC++. The simulation results demonstrate that the loop can not only provide the realistic 3D effect but also represent the yarn texture. Hence, it can be used as a knitted fabric simulation method and applied in the CKCAD knitting system successfully; comparison with common CAD programs, this system can show the loop appearance directly during the design process and make this work more intuitive and evocative.

2. Geometrical Model of the Yarn and Loop and the Texture Features

The geometrical model for the surface of the yarn: The yarn's geometrical model is simplified as a rectangle whose width is the diameter of the yarn (d) and length is the cyclic length of the unit of the yarn (l), as shown in Figure 1(a).

The geometrical model for the loop selects the representative Peirce loop model [12]. This model is relatively simple, consisting of straight lines and arcs; there are advantages in the system operation speed; while the model is too idealistic, but it has been able to reflect the loop structure clearly. The geometrical model for the loop is the fragmented geometrical shape. The weft plain stitch is symmetric figure, with a height *H* and width *W*. Consider the left of the symmetry axis, which consists of three sections. From bottom up, the first section: a quarter of a circle with the point *O2* as the center, the radius of the internal circle is *r*, and the model assumes that *r* is equal to the yarn diameter *d*, so the radius of the external circle is *2d*. The second section: the parallelogram with a height of *P* and a bottom side length of *d*. The third section: a quarter of a circle with a center *O1* and a radius *r* of the internal circle. In the model, we set *H:W* = 2:1, so *P = W = 4d*, and *H = 8d,* as shown in Figure 1(b).

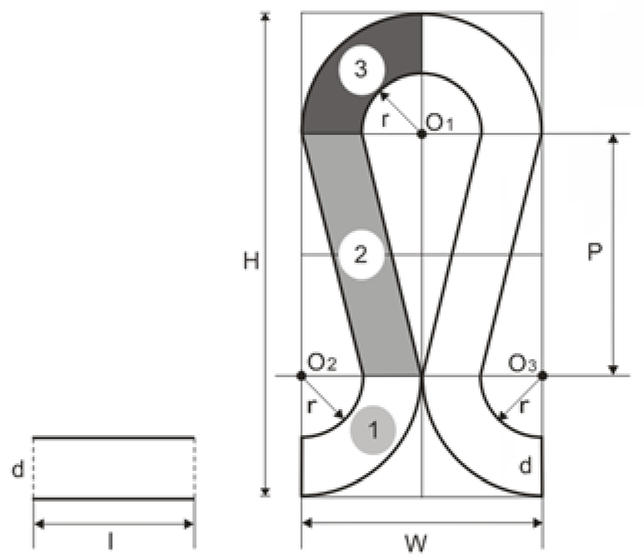


Figure 1 Geometric model of yarn (a) and loop (b).

As the yarn is the building block of the fabric, the simulation result of the yarn's reality determines the simulation result of the fabric. The texture features of the yarn include not only the thickness and color but also the hairiness [13], sense of reality, and twist. The loop consists of the bent yarns. In addition to the texture of the yarn, the loop has spatial continuity. For example, the yarn's texture varies continuously based on the bending of the loop, and this can be especially seen from the variation of the twist. The use of several circles to constitute the fold yarn, coupled with twistification, provides an effective approach to twist continuity, but the texture at the surface is disappointing. The yarns can form the loop via catenation in the 3D space, endowing the texture at the surface of the loop with the brightness-varying spatial sense. Hence, the focus of this paper is to improve the lifelikeness of the loop via continuous texture of the loop and the optimization of the loop's brightness based on the yarn's texture.

3. Mathematical Model for Mapping the Yarn Texture into the Loop

3.1 Mathematical model of the yarn texture and the loop texture

If each pixel in the yarn's model is regarded as an element and each element has three color properties (i.e., R, G, and B), then the yarn texture can be converted into a 2D matrix, called the texture matrix *W*:

$$\mathrm{W} = \begin{bmatrix} w_{1,d} & \cdots & w_{l,d} \\ \vdots & w_{i,j} & \vdots \\ w_{1,1} & \cdots & w_{l,1} \end{bmatrix} \tag{1}$$

where *wi,j* denotes the RGB value of the pixel in the yarn texture, *i* denotes the horizontal index, *j* denotes the vertical index, *d* denotes the total height of the pixels in the texture, and *l* denotes the cyclic unit length of the yarn texture, as shown in Equation (1).

Similarly, the loop texture can be converted into a 2D matrix *S*:

$$\mathrm{S} = \begin{bmatrix} s_{1,8d} & \cdots & s_{4d,8d} \\ \vdots & s_{x,y} & \vdots \\ s_{1,1} & \cdots & s_{4d,1} \end{bmatrix} \tag{2}$$

where *sx,y* is the RGB value of the pixel in the loop texture, *x* is the horizontal index, *y* is the vertical index, *8d* is the total height of the pixels in the loop texture, and *4d* is the width of the loop texture, as shown in Equation (2).

3.2 Transformation between the loop texture and the yarn texture

To obtain the loop texture, the relationship between *x, y* coordinates and *d, i, j* should be constructed with the given yarn diameter *d* and the yarn texture matrix. Because the loop model is a fragmented geometrical shape, the transformation function has to be defined for different fragments. To ensure the continuity of the loop's left and right texture, the values of the pixels cannot be determined symmetrically. Hence, the loop is fragmented into six parts, each of which has different ranges for *x* and *y*. The points in each range has to satisfy relevant conditions before computing the corresponding relation. The specified conditions can reduce computational loads. The textures are fitted in the sequence from 1 to 6, as shown in Figure 2.

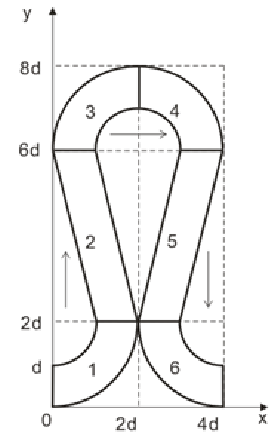


Figure 2. Loop texture partition

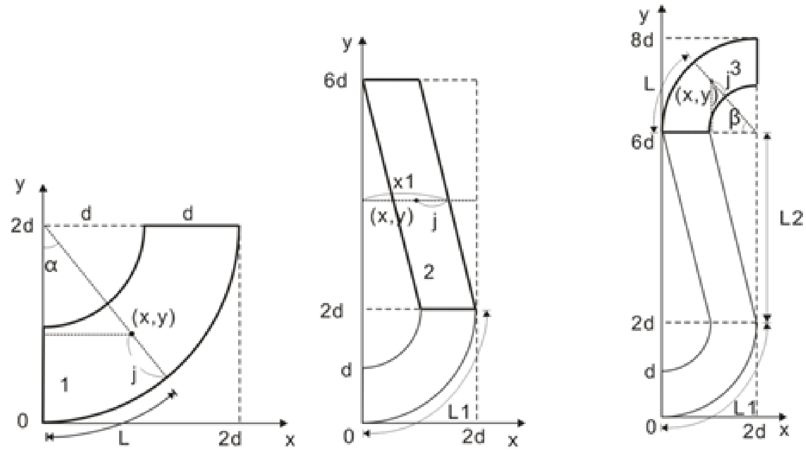


Figure 3. Different region of loop texture partition: (a) Region 1, (b) Region 2, and (c) Region 3

Region 1:

The transformation relation of the first region is illustrated in the Figure 3(a).

$$\mathrm{i} = \mathrm{L} - n \times l = (2d \times \alpha) - n \times l \;\; = (2d \times \tan^{-1} \frac{x}{2d - y}) - n \times l \qquad n \in N$$

$$\mathrm{j} = 2\mathrm{d} - \sqrt{x^2 + (2d - y)^2}$$

$$\mathrm{S(x,y)} = \mathrm{W}\left(2d \times \tan^{-1} \frac{x}{2d - y} - n \times l, 2d - \sqrt{x^2 + (2d - y)^2}\right) \qquad (3)$$

The range of value is $0 < x \leq 2d,\ 0 < y \leq 2d$.

The calculation condition is $d < \sqrt{x^2 + (2d - y)^2} \leq 2d$.

Region 2:

The transformation relation of the first region is illustrated in the Figure 3(b).

$$\mathrm{i} = \mathrm{L} - n \times l = (2d \times \alpha) - n \times l \;\; = (2d \times \tan^{-1} \frac{x}{2d - y}) - n \times l \qquad n \in N$$

$$\mathrm{j} = 2\mathrm{d} - \sqrt{x^2 + (2d - y)^2}$$

$$\mathrm{S(x,y)} = \mathrm{W}\left((\pi d + y - 2d) - n \times l, \frac{10d - y}{4} - x\right) \qquad (4)$$

The range of value is $0 < x \leq 2d,\ 2d < y \leq 6d$.

The calculation condition is $\frac{6d-y}{4} < x \leq \frac{10d-y}{4}$

Region 3:

The transformation relation of the first region is illustrated in the Figure 3(c).

$$\mathrm{i} = (\mathrm{L1} + \mathrm{L2} + \mathrm{L}) - n \times l \quad = (\pi d + 4d + 2d \times \beta) - n \times l$$

$$= \left(\pi d + 4d + 2d \times \tan^{-1}\frac{y - 6d}{2d - x}\right) - n \times l \quad n \in N$$

$$\mathrm{j} = \sqrt{(2d - x)^2 + (y - 6d)^2} - d$$

$$\mathrm{S(x,y)} = \mathrm{W}(\left(\pi d + 4d + 2d \times \tan^{-1}\frac{y - 6d}{2d - x}\right) - n \times l \ , \sqrt{(2d - x)^2 + (y - 6d)^2} - d) \quad (5)$$

The range of value is $0 < x \leq 2d,\ 6d < y \leq 8d.$

The calculation condition is $d < \sqrt{(2d - x)^2 + (y - 6d)^2} \leq 2d.$

The methods for computing the textures of the six regions can be acquired similarly; the other region computing formulas are shown as follows:

Region 4:

$$\mathrm{S(x,y)} = \mathrm{W}\left(\left(2\pi d + 4d + 2d \times \tan^{-1}\frac{x - 2d}{y - 6d}\right) - n \times l \ , \sqrt{(x - 2d)^2 + (y - 6d)^2} - d\right) \quad (6)$$

The range of value is $2d < x \leq 4d$, $6d < y \leq 8d.$

The calculation condition is $d < \sqrt{(x - 2d)^2 + (y - 6d)^2} \leq 2d.$

Region 5:

$$\mathrm{S(x,y)} = \mathrm{W}\left((3\pi d + 4d + 6d - y) - n \times l \ , x - \frac{6d + y}{4}\right) \quad (7)$$

The range of value is $2d < x \leq 4d$, $2d < y \leq 6d.$

The calculation condition is $\frac{6d+y}{4} < x \leq \frac{10d+y}{4}$

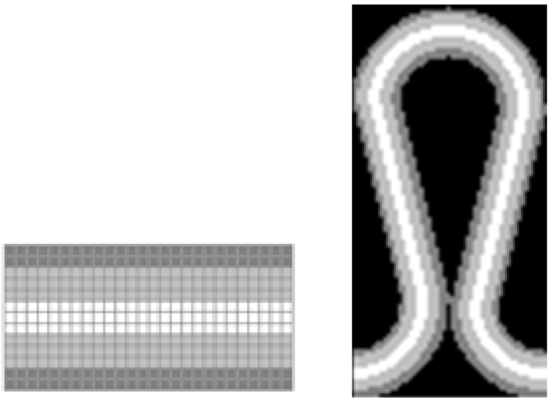
Region 6:

$$\mathrm{S(x,y)} = \mathrm{W}((3\pi d + 8d + 2d \times \tan^{-1}\frac{2d - y}{4d - x}) - n \times l, 2d - \sqrt{(4d - x)^2 + (2d - y)^2}) \quad (8)$$

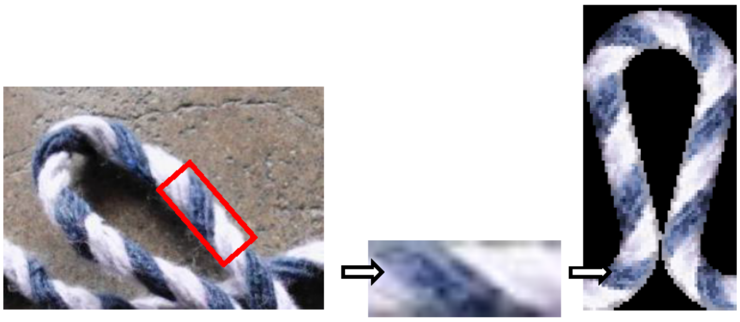
The range of value is $2d < x \leq 4d$, $0 < y \leq 2d.$

The calculation condition is $d < \sqrt{(4d - x)^2 + (2d - y)^2} \leq 2d$

According to the equation (3)–(8), experiments with simple textures are performed to prove the effectiveness of the proposed algorithm. Figure 4(a) shows the cyclic unit of the simple texture with a height of 13 pixels and a width of 26 pixels. The loop texture fitted with the above algorithm is shown in Fig. 4(b). It can be seen that the yarn texture is continuous along the loop flexibility. Figure 5(a) shows the common image of yarn; Fig. 5(b) shows the cyclic unit of the yarn's colorful texture extracted from the image. Figure 5(c) shows the loop generated by the algorithm. It can be seen that the proposed algorithm is also applicable to the complicated colorful texture. Note that the yarn texture can remain continuous in the loop but the joint between loops



(a) (b)
Figure 4. Simple texture (a) and loop simulation (b)



(a) (b) (c)
Figure 5. Colorful yarn image (a);Colorful texture (b), and loop simulation (c)

may be discontinuous. Only when the texture length is the common divisor of the loop length, the joint between the loops will be continuous. The total length of the loop computed by the proposed algorithm is 20*x* the height of the texture and can be used as a pointer for selection of the texture length.

4. Processing of the Loop's Brightness

Parts of the loop may be blank, resulting in variation of brightness in the loop [14]. The abovementioned method simply maps the straight yarn texture to the planar geometrical shape of the loop, so it is unable to provide the 3D appearance. The brightness of the planar shapes needs to be varied to make the loop more real. This can also represent the joining relationship between loops. Different ways of joining the loops lead to different illuminations of the loops. Hence, the types of joining relationships between loops need to be studied first before we investigate the brightness variation of the loops.

4.1 Ways of joining the loops

The loop can be mainly classified into the looping, tuck, and float. The float is straight without any brightness variation of the yarn. The yarns of tuck and loop bend in the 3D space and the brightness varies, especially for the loop. Consider the structure of loop. There are four ways of joining the loops: the face loop joins the face loop, the back loop joins the back loop, the face loop joins the back loop, the back loop joins the face loop, as shown in Figure 6.

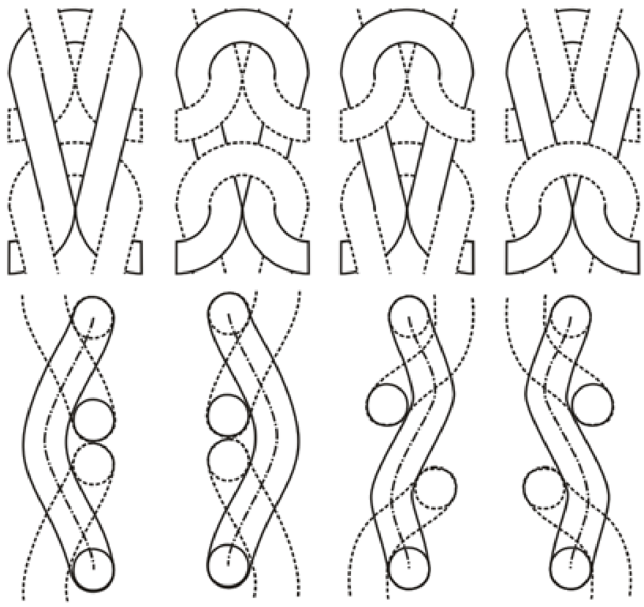


Figure 6 Different ways of joining the loops

4.2 Brightness variation curve of the loop

Based on the study into the structural variation of the loops above, the bending curves at the surface of the yarns are extracted as the ideal brightness variation curve. Taking the continuity between loops into account, the same brightness is chosen as the starting point as shown in Figure 7, where the *x*-axis denotes the percentage variation of the loop's height; the *y*-axis denotes the percentage variation of the loop's brightness; *a* denotes the original brightness of the loop; and *b*, *c*, *d*, and *e* denote the ideal brightness variation curves of the textures at the surface of the face loop, back loop, face loop transfer to back, and back loop transfer to front, respectively.

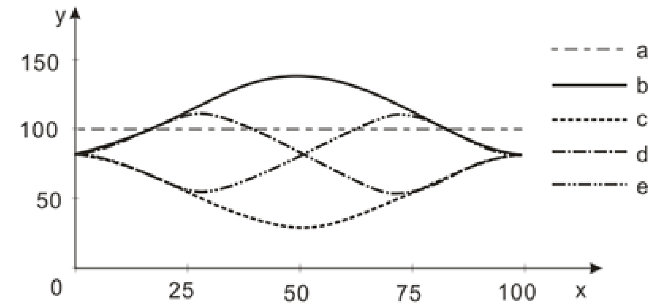


Figure 7 Different ways of joining the loops

The curves *b* and *c* follow the cosine pattern; the curve *d* increases smoothly at first, falls, and then rises again; and the curve *e* is just the opposite. The equations of the four curves are given in equations (9)–(12):

$$L_b = L_0 + \frac{L_{max} - L_0}{2} - \frac{L_{max} - L_0}{2}\cos\left(x \times \frac{2\pi}{H}\right) \tag{9}$$

$$L_c = L_0 - \frac{L_0 - L_{min}}{2} + \frac{L_0 - L_{min}}{2}\cos\left(x \times \frac{2\pi}{H}\right) \tag{10}$$

$$L_d = L_0 + (L_{max} - L_0 - \Delta)\sin\left(x \times \frac{2\pi}{H}\right) + 2\Delta\sin\left(x \times \frac{4\pi}{H} + \pi\right) \tag{11}$$

$$L_e = L_0 + (L_{max} - L_0 - \Delta)\sin\left(x \times \frac{2\pi}{H} + \pi\right) + 2\Delta\sin\left(x \times \frac{4\pi}{H}\right) \tag{12}$$

where *Lb, Lc, Ld,* and *Le* denote the brightness variation curves of the four wreathed loops, *L0* denotes the original brightness, *Lmax* denotes the specified maximum brightness, *Lmin* denotes the minimum value, *H* denotes the height of the loop, is the adjustment parameter, and a high value ofmeans that the starting and ending curves of *d* and *e* are smooth and the intermediate variations are substantial. *L0* is set to 80%, the maximum value of *b* is 140%, the minimum value of *c* is 40%, and the maximum values of *d* and *e* are 110%, is set to 3. Figure 8 shows the loop with varying brightness. Compared with Figure 8(a), which is not processed with varying brightness, the textures at the surface of the loops in Figure 8(b), (c), (d), and 8(e) are processed with varying brightness have varied brightness. They bulge and dip; bulge first and then dip; dip first and then bulge in a 2D manner, respectively, creating the 3D effect.

5. Computer Implementation of the Loop Simulation

The simulation of the transformation from the yarn texture to the loop texture using the proposed algorithm is implemented with VC++. The data structure is described as follows:

struct TEXTURES{int r; int g; int b}textures;

vector<vector<struct TEXTURES>> *W*;

vector<vector<struct TEXTURES>> *S*;

Each texture has three data elements (R, G, and B). *W* and *S* are the dynamic texture-type 2D array. The process to derive *S* from *W* is shown in Figure 9.

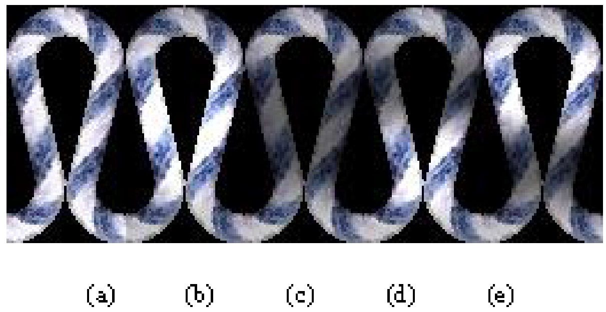


Figure 8 Loop with varying brightness

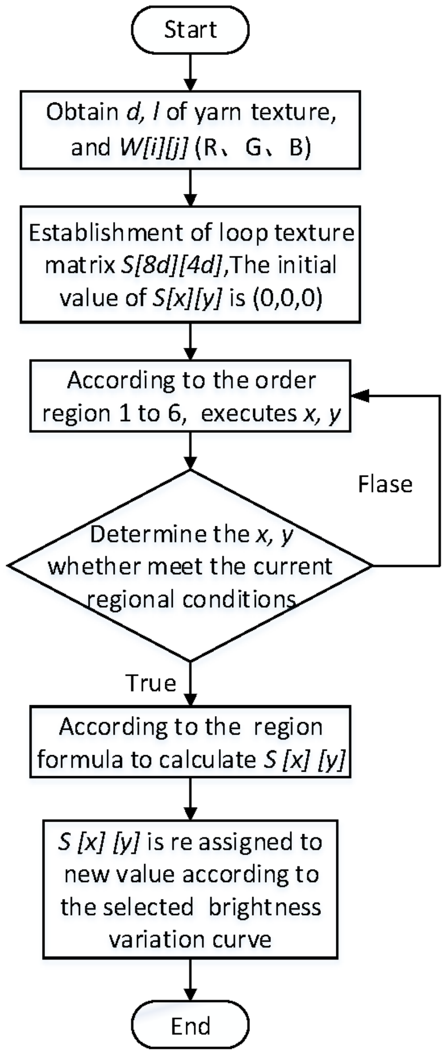


Figure 9 Algorithm flow chart

The program get the S matrix by region formulas (3)–(8), then change the RGB value according to the brightness formulas (9)–(12), the RGB values of all data in the matrix S formed the loop picture. It takes little time to implement a loop with a height of 100pt and a width of 50pt using the proposed program. By designing the repeat of the experiments, an average period of 546 ms is needed to repeat the process of acquiring the yarn texture, transforming into the loop texture, and changing the brightness of the loop texture for 100 times. That is, the transformation of the yarn into a loop processed with varying brightness takes less than 6 ms. Compared with the 3D texture computation, our proposed method is easy and fast and thus can be used for constructing the primitive of the flat knitting CAD, and the design efficiency will not be affected by the heavy 3D computational loads. Figure 10 shows different knitting stitches that is simulated using loop primitives; generation method will be described in subsequent papers.

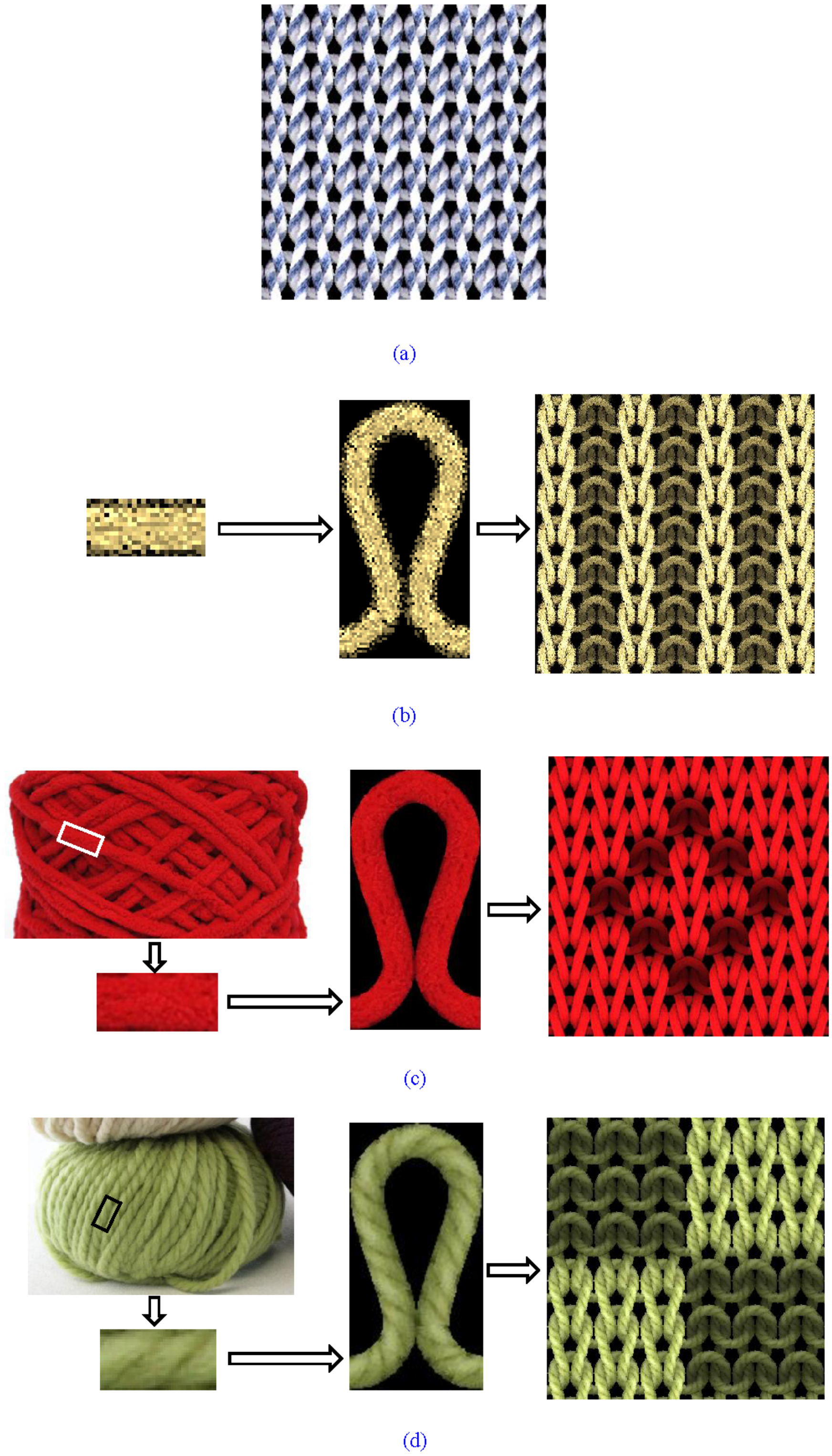


Figure 10 Stitch simulation. (a) Plain jersey stitch, (b) rib stitch, (c) knit and purl stitch 1#, and (d) knit and purl stitch 2#

6. Conclusion

An algorithm that maps the yarn texture to the loop based on the loop geometrical model is proposed in this paper. Experiments show that the proposed method can ensure the continuity of the yarn texture in the bending loops; changes in brightness make the loop look like three dimensional; the experiment of different texture prove that this method can provide great realistic appearance of loops; more importantly, the program running speed is more fast than 3D simulation; this method is helpful for constructing the loop primitive of the realistic fabrics.

Construct the yarn texture model and the loop texture model as well as the region-wise model for the transformation from the yarn texture to the loop texture using the loop geometrical model. Taking the knitted loop as the example, study the morphologic changes of the 3D loop, construct the ideal curvilinear function describing the brightness variation at the loop surface, achieve the spatial concave-convex sense of the loop, and improve the reality of the loop texture. The loop primitive generation programs for extracting the yarn textures, mapping the yarn to the loop, and changing the brightness of the loop texture are implemented by VC++, providing simple and realistic primitives for the loop-based fabric design.

This paper just studies the simulation of the knitted loop. Further work needs to be done on tuck, loop transfer, as well as the loop texture that has special texture to be formed by the fancy yarn.

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